ACTIVE AND PASSIVE MICROWAVE REMOTE SENSING OF SNOW AT LARGE SPATIAL SCALES

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1. SENSITIVITY ANALYSIS

The behavior of Ku band active and K and Ka band passive spaceborne data at large spatial scales has been compared to the variation of snow depth along five seasons (1999-2004) over different locations in the Northern hemisphere. Three distinct behaviors are generally observed: 1) both backscattering and spectral gradient increase as snow depth increases; 2) the spectral gradient starts decreasing in the middle of the snow season where the backscattering increases for the whole season; and 3) both backscattering and spectral gradient increase up to a certain time of the snow season and then they decrease, although snow depth is still increasing. A preliminary explanation is that the behavior of the electromagnetic quantities relates to the stratigraphy of the snow pack as well as the air temperature. The presence of multiple layers with coarse snow crystals reduces the values of the K band brightness temperature, hence reducing the spectral gradient. In the active case, the radiation backscattered by large crystals is attenuated by the new snow on top of old layers resulting in a decrease on the backscattering coefficient. This aspect is fundamental for the development of future active/passive combined retrievals as it is generally assumed that the spectral gradient or backscattering increases with snow depth, over land.

2. COMPARISON OF DYNAMIC RANGES

The dynamic range of spaceborne Ku band scatterometer data with respect to the snow depth at very large spatial scales has been quantified and compared it with the dynamic range for the passive case. Results show that dynamic ranges in active and passive cases are strongly correlated (R^2=0.93), suggesting that QuikSCAT data have a sufficient dynamic range to monitor snow depth at large spatial scale.

In order, to compare the dynamic range of the active and passive datasets to snow depth, a Normalized Dynamic Range (NDR) was defined, dividing the dynamic range by snow depth. The figure below figure shows NDR in the passive case (NDRpassive, x-axis) versus the NDR in the active case (NDRactive, y-axis). The NDRactive ranges between 0.06 and 0.18 dB/cm where the NDRpassive ranges between 0.55 and 1.13 K/cm. A visual analysis of the figure suggests that the NDRpassive and NDRactive are well-correlated. If we fit NDRactive vs. NDRpassive then we obtain the following expression NDRactive=0.1889*NDRpassive-0.0653 with R^2=0.93. This result shows that the two NDR are strongly correlated with the fraction of variability in the active case that can be explained by the variability in passive one.

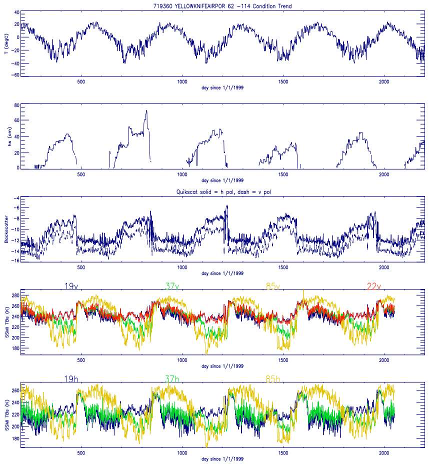

Fig. 1 The temporal trend of air temperature (upper plot), snow depth (second plot from the top) recorded by the WMO station, QuikSCAT backscattering coefficients at vertical and horizontal polarizations (third plot from the top), SSM/I brightness temperatures, vertical polarization (second plot from the bottom) and horizontal polarization (bottom plot) for the Yellowknife Airport (WMO # 718380, Lat. 62.46 N, Lon –114.45 E).

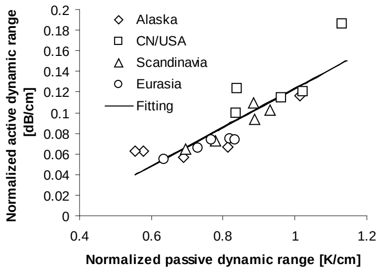

Fig. 2 Normalized passive vs. active dynamic ranges

3.STATISTICAL ANALYSIS BETWEEN MICROWAVE DATA AND SNOW DEPTH

The relationship between microwave data and snow depth can be written in a general form as follows:

$$SD = f(MW)+const$$

Both a linear and a non-linear form of the function *f* were considered to investigate the benefits of the combination of active and passive data. The expression considered in the linear approach is the following in the case of both active and passive data:

$$SD = A\cdot(Tb19V - Tb37V)+B\cdot(\sigma 13.4V)+C$$

Instead, in the case of only passive or active data the following expressions are used:

$$SD = A\cdot(Tb19V - Tb37V) +C \qquad \text{Passive}$$
$$SD = B\cdot(s13.4V)+C \qquad \text{Active}$$

The potential improvement on the snow depth retrieval related to the combined use of active and passive data was quantified by evaluating the root mean square error (RMSE), the regression coefficient and the coefficient of determination. In general, best results were obtained when both active and passive data were used, with respect to the use of passive or active data solely. The maximum and average values of *RMSE* improvement were, respectively, 24.65 % and 7.6 %. In the case of the coefficient of determination *R2*, the maximum and average values of improvement were, respectively, 42 % and 6 %.

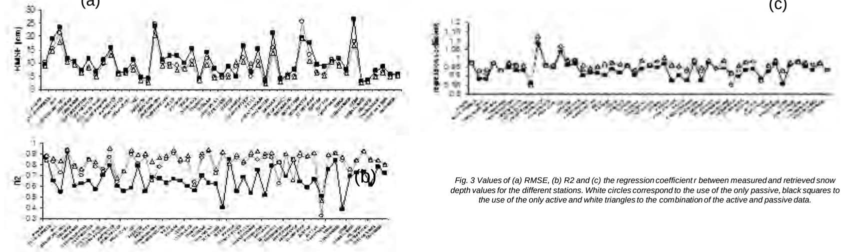

Fig. 3 Values of (a) RMSE, (b) R2 and (c) the regression coefficient r between measured and retrieved snow depth values for the different stations. White circles correspond to the use of the only passive, black squares to the use of the only active and white triangles to the combination of the active and passive data.

4. EXAMPLE OF MAPS

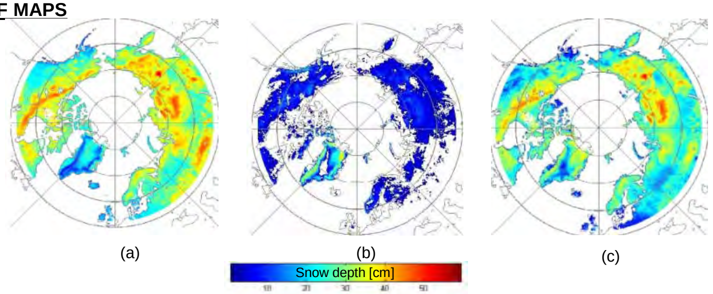

Fig. 4 Example of snow depth obtained by using (a) the only passive data, (b) the only active data and (c) \both active and passive data for December 8, 2002.

5. IMPROVEMENT OF QUIKSCAT VS. X-BAND AMSR-E BRIGHTNESS TEMPERAUTRES

	RMSE			R²			Offset		
	K, Ka	*K, Ka, Ku*	*K, Ka, X*	*K, Ka*	*K, Ka, Ku*	*K, Ka, X*	*K, Ka*	*K, Ka, Ku*	*K, Ka, X*
Olekminsk (RA)	7.01	6.59	6.63	83.40	85.87	85.68	13.40	11.84	11.96
Dudinka (RA)	11.70	11.68	11.46	84.64	84.68	85.44	19.62	19.58	18.82
Bor (RA)	12.74	12.11	12.68	83.45	85.50	83.64	28.15	25.45	27.91
Skwentka (AK)	14.91	14.81	14.88	72.99	73.57	73.15	45.80	45.21	45.63
Sutton (AK)	19.74	19.18	19.34	43.37	54.78	52.23	36.49	34.42	35.01
Sodankyla (FI)	9.28	9.27	9.25	85.23	85.25	85.34	12.12	12.11	12.05
Rovaniemi (NO)	6.52	6.40	6.44	88.63	89.14	88.99	7.09	6.82	6.90
Kuopio (FI)	5.85	5.74	5.81	92.92	93.21	93.04	4.47	4.30	4.40
Agata (RA)	15.05	11.42	12.92	44.62	81.74	73.53	59.69	34.41	43.99
Jakutsk (RA)	4.11	3.91	3.37	91.45	92.36	94.53	4.73	4.29	3.17
Pokrovskaja (RA)	3.23	3.22	2.64	92.56	92.65	95.23	4.69	4.64	3.13
Yellowknife (CA)	4.97	4.95	4.71	93.60	93.66	94.32	5.43	5.38	4.87
Fairbanks (AK)	7.93	7.91	7.92	88.27	88.32	88.29	12.55	12.51	12.54

Table 1. RMSE, R2 and offset for selected stations when using a) only passive data at K and Ka bands, b) the passive data at K and Ka bands with the active data at Ku band and c) only the passive data at K, Ka and X band for some selected stations.

6. CONCLUSIONS

The combination of active and passive data provided better statistics between satellite data and snow depth data than passive data alone at K and Ka bands. The reason of the improvement needs to be further investigated and this is being done by analyzing active and passive data at high (ground) and medium (airborne) spatial resolution. Snow parameters are derived over extended areas from the outputs of a snow/hydrology model and are used as inputs to an electromagnetic model. However, it must be pointed out here that results obtained using the brightness temperatures at X-band were as good as or better than those obtained when using the active data. Brightness temperatures at X band are available only since May 2002, measured by the AMSR-E flying on board of the AQUA satellite where QuikSCAT data are available since 1999 (NSCAT data also are available between 1997 and 1999). As a consequence, for the period 1997 – 2002 the use of combined active and passive microwave data can offer an improvement on the retrieval of snow depth with respect to the use of passive data at K and Ka band. After May 2002, it might not be necessary to combine active and passive data because the use of X, K and Ka band data could provide similar results. An analysis of the performance of the two approaches in the period 2002 – to date is the scope of an ongoing investigation.

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